7

Conducting Analyses

Careful and complete analysis of the data collected following an accident is critical to the accurate determination of an accident's causal factors. The results of properly performed analyses provide the basis for corrective and preventive measures.

The analysis portion of the accident investigation is not a single, distinct part of the investigation. Instead, it is the central part of the iterative process that includes collecting facts and determining causal factors. Well chosen analytic methods, carefully performed, yield the most useful data and aid investigators in developing an investigation report that has sound judgments of need.

Caution must be taken in applying analytic methods. Analytic techniques cannot be used mechanically and without thought. The best analytic tools can become cumbersome and ineffective if they are not applied to an accident's specific circumstances and adapted accordingly. Moreover, no single method will accomplish all the analyses required to determine the multiple causal factors of an accident. Several complementary techniques that are coordinated and cross validated should be used to yield optimal results.

TIP

Each board should determine which analytic techniques to use based on the accident's complexity and severity. Alternative approaches and methods to those presented in this workbook are acceptable, provided that they meet the requirements of DOE Order 225.1 and are demonstrably equivalent.

This section of the workbook begins with a case study of an electrical accident. It is referenced throughout this and subsequent sections to illustrate the process of determining of facts and the use of six analytic techniques: four core techniques commonly used in DOE accident investigations, and two tree-based techniques. In this workbook, particular emphasis is placed on these techniques because they can be used in most accident investigations. However, for extremely complex accidents, additional, more sophisticated techniques may be needed that require specialized training. Training for these techniques is beyond the scope of this workbook and can be obtained through government, private, and university sources. Further information can be provided by the Program Manager.

CASE STUDY: ACCIDENT DESCRIPTION

The accident occurred at approximately 9:34 a.m. on January 17, 1996, in Building XX, during the excavation of a sump pit in the floor of the building. Workers were attempting to correct a waste stream outfall deficiency. Two workers arrived at the job site at approximately 8:40 a.m. and resumed the excavation work begun the previous day. The workers were employed by WS, the primary subcontractor for construction and maintenance. They used a jackhammer, pry bar, and shovel to loosen and remove the rubble from the sump pit. At about 9:34 a.m., at a depth of 39 inches, Worker A, who was operating the jackhammer, pierced the conduit containing an energized 13.2 kV electrical cable. The accident victim was transported to the local medical center, where cardiac medications were administered.

7.1 Determining Facts

Immediately following any serious accident, much of the information available is conflicting and erroneous. The volume of data expands rapidly as witness statements are taken, emergency response actions are completed, and the accident scene is observed by more individuals.

The principal challenge of the investigation board is to distinguish between accurate and erroneous information in order to focus on areas that will lead to the accident's underlying causes. This can be accomplished by:

- Understanding what activity was being performed at the time of the accident
- Personally conducting a walkthrough of the accident scene
- Challenging "facts" that are inconsistent with the physical evidence
- Corroborating facts through interviews
- Analyzing pertinent components to determine failure modes
- Reviewing policies, procedures, and work records to determine the level of compliance or implementation.

Causal factors of an accident are identified by analyzing the facts gathered earlier in the investigation. Judgments of need, corrective actions, and future preventive measures are determined based on the causes of the accident. Therefore, the facts are the foundation of all other parts of the investigative process and drive the preventive measures as determined by the judgments of need.

TIP

Prevention is at the heart of the entire investigation process; therefore, any accident investigation must focus on fact-finding, not fault-finding.

Fact-finding begins during the collection of evidence. All sources of evidence

(e.g., accident site walkthroughs, witness interviews, physical evidence, policy or procedure documentation) contain facts that, when linked, create a chronological depiction of the events leading to an accident. Facts do not contain hypotheses, opinions, analysis, or conjecture. However, not all facts can be determined with complete certainty, and such facts are referred to as assumptions. Assumptions should be reflected as such in the investigation report and in any closeout briefings.

Board members should immediately begin developing a chronology of events as facts and evidence are collected. Facts should reviewed on an ongoing basis to ensure relevance and accuracy. Facts and evidence later determined to be irrelevant should be removed from the accident chronology and retained in the official investigation file for future consideration.

Contradictory facts can be resolved in closed board meetings, recognizing that the determination of significant facts is an iterative process that evolves as gaps in information are closed and questions resolved. The board revisits the prescribed scope and depth of their investigation often during the fact-finding and analysis process. Doing so ensures that the investigation adheres to the parameters prescribed in the board's appointment memorandum.

CASE STUDY: ACCIDENT FACTS

Using the case study accident, the following three factual statements were derived during the investigation:

- The accident victim had not completed safety training prior to the accident, as required by WS Environment, Safety, and Health Manual Procedure 12340.
- Design drawings for the project on which the injured employee was working did not comply with the requirements of DOE Order 6430.1A, *General Design Criteria*, and did not show the location of the underground cable.
- A standing work order system, without a safety review, was used for nonroutine, nonrepetitive tasks.

7.2 Defining Topics for Analysis

In general, the board should consider five factors when analyzing information (sometimes referred to as the five Ms):

- **Man** (personnel)
- **Machine** (equipment)
- **Media** (work environment)
- **Management** (management controls and systems)
- **Mission** (specific work assignments and, more generally, facility operational assignments).

Human factors; equipment failures; inadequate procedures, policies, or requirements; and inadequate management controls can all play a role in the causes of accidents. Thoroughly and systematically examining these five factors can help the board identify the various causes of an accident.

It is widely accepted in the safety community, and within DOE, that accidents are often indicators of inadequate management controls. *Some safety professionals have gone so far as to say that every accident, regardless of magnitude, is a failure of the organization.* In applying any analytical methods, management and safety systems must be considered as potential contributing factors in an accident, along with other appropriate factors.

Management systems can and should be identified without assigning individual fault. However, identifying a level of management whose actions or lack of control contributed to an accident does not breach the "fact-finding and not fault-finding" premise. DOE Order 225.1 states that accident investigation boards are directed and empowered to investigate causal factors up to and beyond the level of the appointing official and to fully report the results. Failing to do so could lead to a similar or potentially more severe accident.

Using the safety management template (Appendix D) and criteria for guiding principles provided in Section 6 as lines of inquiry, the accident investigation board is responsible for reviewing the adequacy of management system controls impacting the accident under investigation and using the analytic methods as a means of examining whether management system controls were causal factors.

7.3 Using the Core Analytical Techniques

The national programs developed during the last four decades, including those in aerospace, nuclear weapons, and nuclear energy, had the potential for severe economic and public safety consequences and therefore required enormous pre-planning and readiness to prevent errors and failures. During this time, government agencies, private institutions, and universities devoted extensive resources to developing hundreds of analytical methodologies. Analytic techniques used to examine risks, unplanned and undesired events, and sequences of events were the basis of these programs. Many analytical methods were developed to identify lessons learned that, when incorporated into these programs, enhanced their quality and decreased the probability of catastrophic events and consequences. These techniques have been modified, refined, and tailored for a variety of other applications, including accident investigations.

TIP

The purpose of any analytic technique in an accident investigation is to answer the question — "How did it happen?"

DOE accident investigation boards commonly use four techniques to analyze the factual information they have collected, to identify conditions and events that occurred before and immediately following an accident, and to determine an accident's causal factors. Following are descriptions of and instructions for using these four core analytic techniques:

- Events and causal factors charting and analysis
- Barrier analysis
- Change analysis
- Root cause analysis.

7.3.1 Events and Causal Factors Charting and Analysis

Accidents rarely result from a single cause. Events and causal factors charting and analysis is useful in identifying the multiple causes and triggering conditions and events necessary and sufficient for an accident to occur.

There are several variations of the events and causal factors methodology. Two variations commonly used during DOE investigations include events and causal factors *charting* and events and causal factors *analysis*. The first is a graphical display of the accident's chronology and is used primarily for compiling and organizing evidence to portray the sequence of the accident's events. The second is the application of analysis to determine causal factors by identifying significant events and conditions that led to the accident.

Events and causal factors charting and analysis are used in most accident investigations because they are easy to perform and provide a clear depiction of the data. By carefully tracing the events and conditions that allowed the accident to occur, board members can pinpoint specific events and conditions that, if addressed through corrective actions, would prevent a recurrence.

TIP

The purpose of any investigation is to identify causal factors so that corrective actions sufficient to prevent a recurrence can be developed. To identify causal factors, board members must have a clear understanding of the relationships among the events and the conditions that allowed the accident to occur. Events and causal factors charting provides a graphical representation of these relationships.

Events and causal factors analysis was designed to be a stand-alone technique, but is most valuable when combined with the other three core analytical techniques (i.e., change analysis, barrier analysis, and root cause analysis). It may not be sufficient for extracting potentially obscure causal factors or for differentiating between contributing and root causes.

The **benefits** of events and causal factors charting and analysis include:

- Illustrating and validating the sequence of events leading to the accident and the conditions affecting these events
- Showing the relationship of immediately relevant events and conditions to those that are associated but less apparent— portraying the relationships of organizations and individuals involved in the accident
- Directing the progression of additional data collection and analysis by identifying information gaps
- Linking facts and causal factors to organizational issues and management systems
- Validating the results of other analytic techniques
- Providing a structured method for collecting, organizing, and integrating collected evidence
- Conveying the possibility of multiple causes
- Providing an ongoing method of organizing and presenting data to facilitate communication among the investigators
- Clearly presenting information regarding the accident that can be used to guide report writing
- Providing an effective visual aid that summarizes key information regarding the accident and its causes in the investigation report.

Constructing the Chart. Constructing the events and causal factors chart should begin immediately. However, the initial chart will be only a skeleton of the final product. Many facts and conditions will be discovered in a short amount of time, and therefore, the chart should be updated almost daily throughout the investigative data collection phase. Keeping the chart up to date helps ensure that the investigation proceeds smoothly, that gaps in information are identified, and that the investigators have a clear representation of accident chronology for use in evidence collection and witness interviewing.

Investigators and analysts can construct an events and causal factors chart using either a manual or computerized method. Accident investigation boards often use both techniques during the course of the investigation, developing the initial chart manually and then transferring the resulting data into computer programs.

The manual method employs removable adhesive notes to chronologically depict events and the conditions affecting these events. The chart is generally constructed on a large conference room wall or many sheets of poster paper. Accident events and conditions are recorded on removable adhesive notes and affixed sequentially to the wall in the board's conference room or "command center." Because the exact chronology of the information is not yet known, removable adhesive notes allow investigators to easily change the sequence of this information and to add information as it becomes available. Different colored notes or inks can be used to distinguish between events and conditions in this initial manual construction of the events and causal factors chart.

If the information becomes too unwieldy to manipulate manually, the data can be entered into a computerized analysis program. Using specialized analytical software, investigators can produce an events and causal factors

graphic, as well as other analytical trees or accident models.

Whether using a manual or a computerized approach, the process begins by chronologically constructing, from left to right, the primary chain of events that led to an accident. Secondary and miscellaneous events are then added to the events and causal factors chart, inserted where appropriate in a line above the primary sequence line. Conditions that affect either the primary or secondary events are then placed above or below these events. Figure 7-1 illustrates the basic format of the events and causal factors chart. Guidelines to use in constructing the chart are shown in Table 7-1.

A sample summary events and causal factors chart (Figure 7-2) uses data from the case study accident. It illustrates how data may become available during an accident investigation, and how a chart would first be constructed, and subsequently updated and expanded.

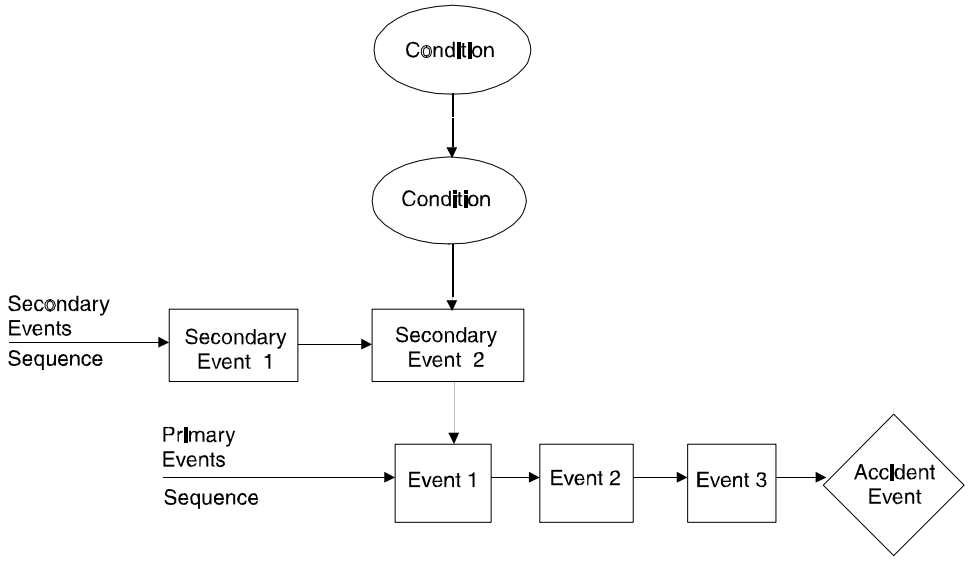
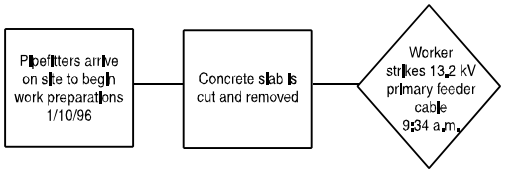


Figure 7-1. An events and causal factors chart links conditions and events to the accident event.

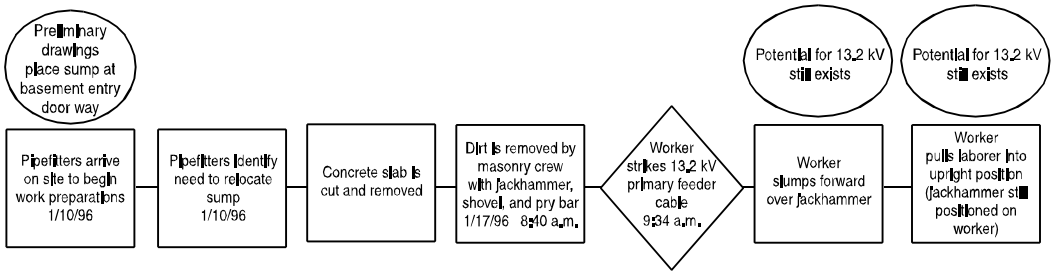
Table 7-1. Guidelines and Symbols for Preparing an Events and Causal Factors Chart.

Symbols	■ □ — Events ■ ♢ — Accidents ■ ⬭ — Conditions ■ ::: — Presumptive events ■ ⬭ — Presumptive conditions or assumptions ■ → — Connect events ■ - -> — Connect conditions ■ ▷ — Transfers one line to another ■ L T A — Less than adequate; a judgment of the board
Events	■ Are active (e.g., "crane strikes building") ■ Should be stated using one noun and one active verb ■ Should be quantified as much as possible and where applicable (e.g., "the worker fell 26 feet," rather than, "the worker fell off the platform") ■ Should indicate the date and time of the event, when they are known ■ Should be derived from the event or events and conditions immediately preceding it.
Conditions	■ Are passive (e.g., "fog in the area") ■ Describe states or circumstances rather than occurrences or events ■ As practical, should be quantified ■ Should indicate date and time if practical/applicable ■ Are derived from conditions immediately preceding it.
Primary Event Sequence	Encompasses the main events of the accident and those that form the main events line of the chart.
Secondary Event Sequence	Encompasses the events that are secondary or contributing events and those that form the secondary line of the chart.

Stage 1:
(Facts available at the time of Board's arrival on site)



Stage 2:
(Facts and conditions known after reviewing witness statements and conducting walk-through)



Stage 3:
(Additional facts obtained from interviews and document reviews. Note few conditions have been determined thus far.)

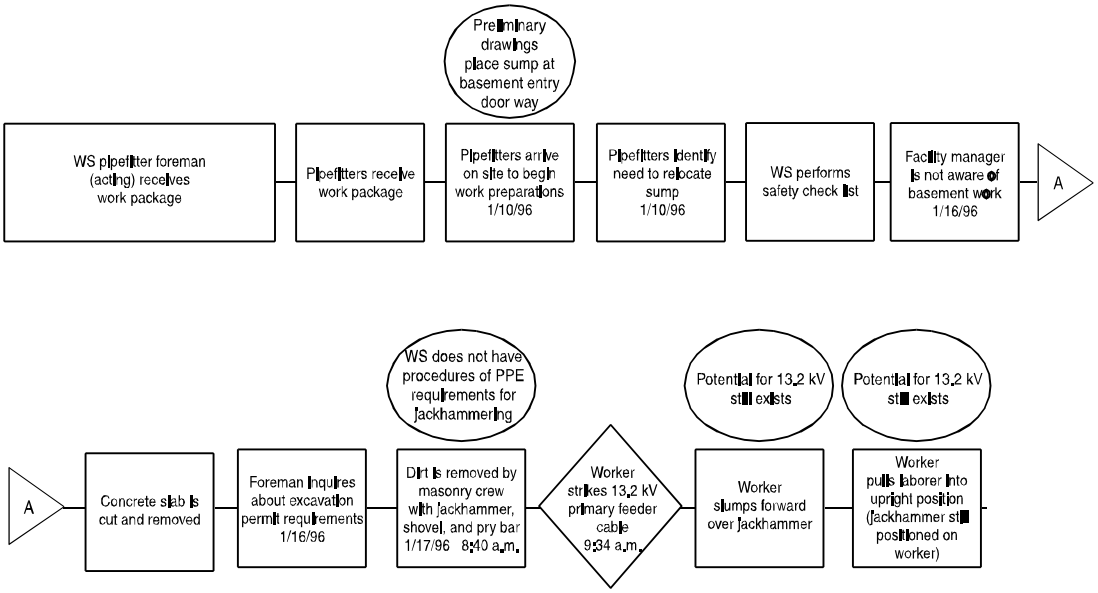


Figure 7-2. As more data become available, an events and causal factors chart can be expanded.

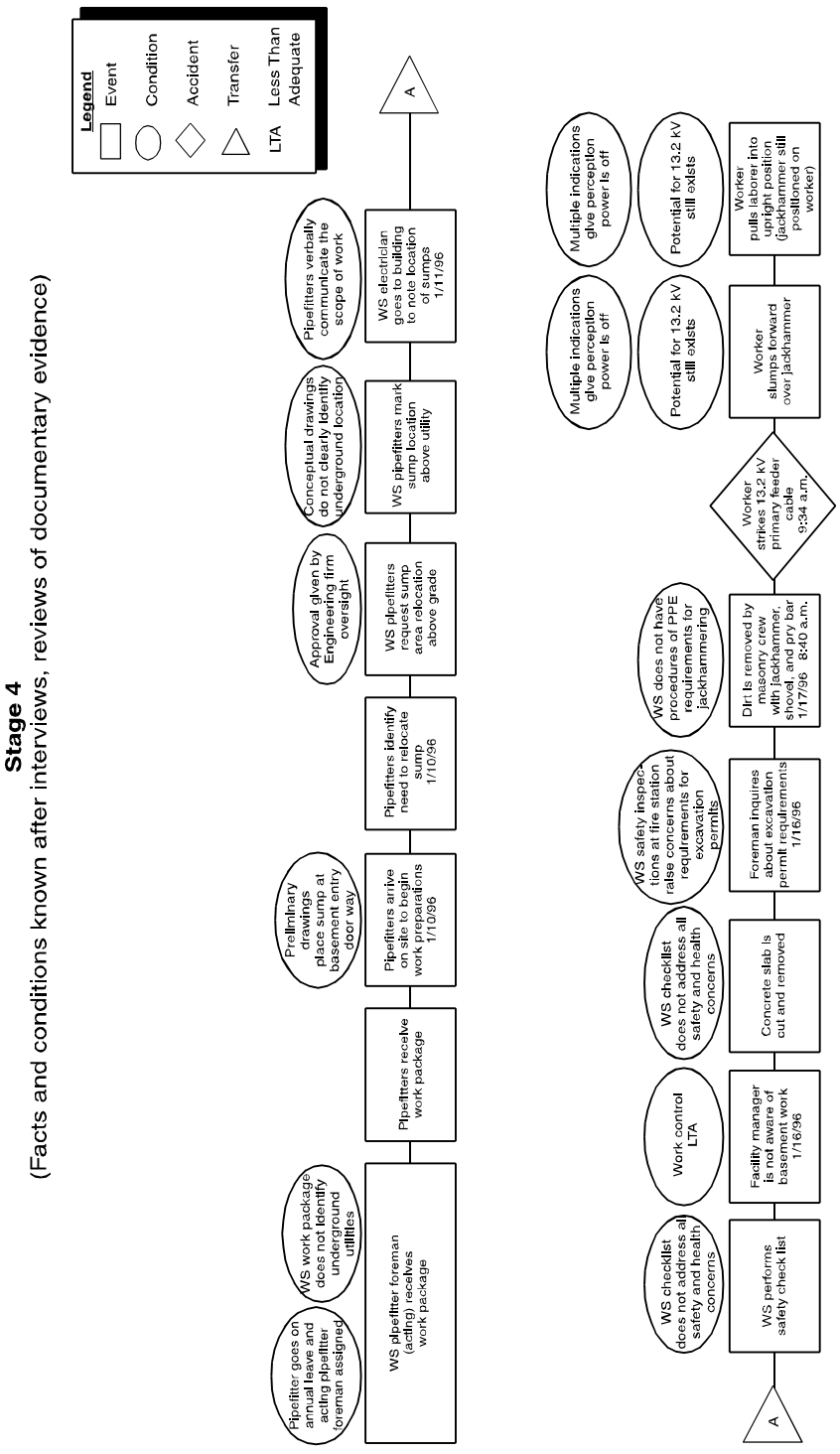


Figure 7-2. (Continued)

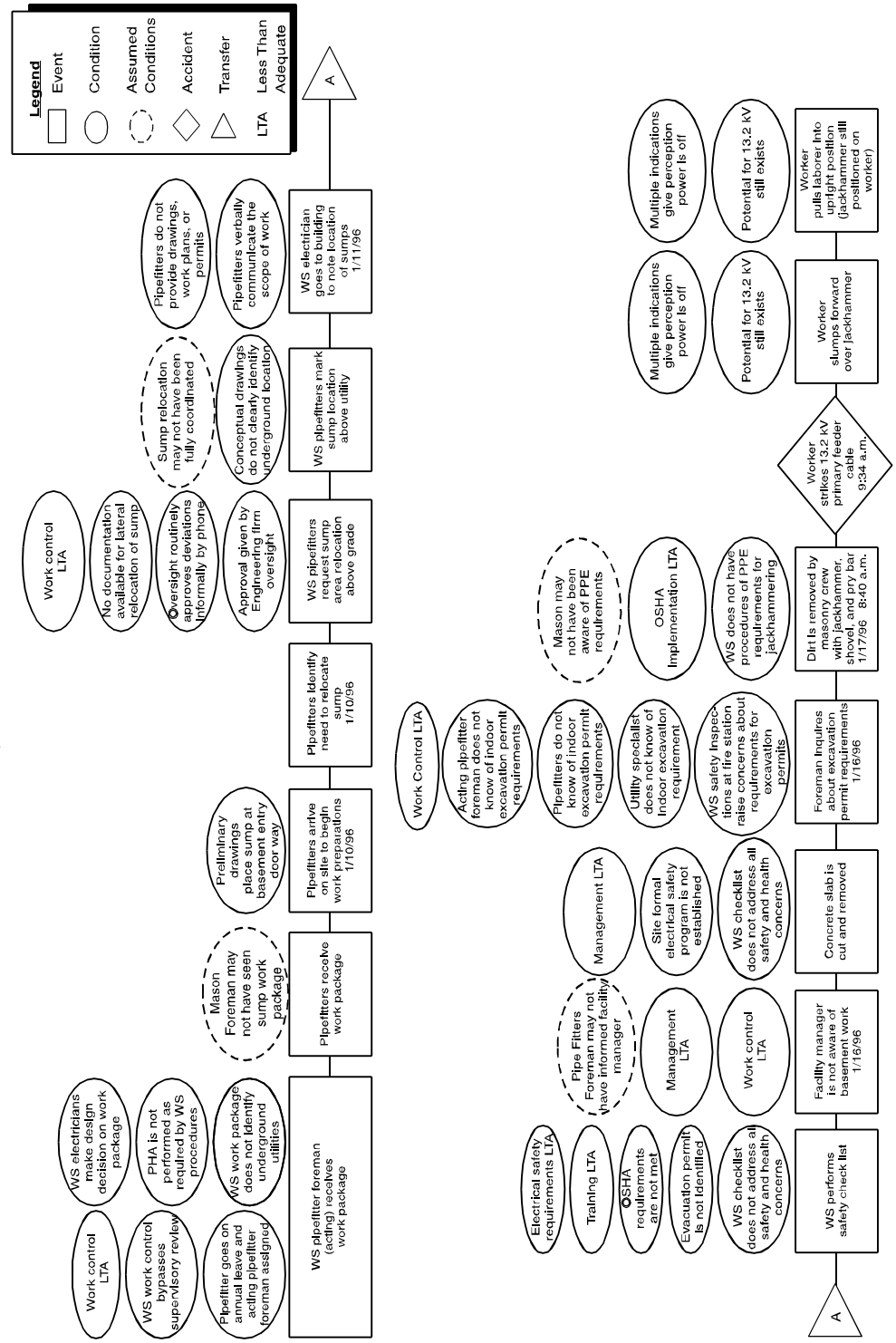


Figure 7-2. (Continued)